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Characterization of Adhesively Bonded Aluminum

Armor through Qualitative Analytical Techniques

April 1982

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**U.S. ARMY TANK-AUTOMOTIVE COMMAND**
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Shear Strength

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Aluminum armor 5083, single lap shear coupons were joined with generic epoxy and urethane adhesive to determine the adhesive effectiveness. Chemical treatment of the aluminum substrate with Methyl Ethyl Ketone (MEK) was also examined to determine its effect on the shear strength. The tests were conducted under atmospheric pressure and a temperature of 70° ± 5°F. Shear strength results indicate that, when applied to an untreated or MEK treated surface with a 60 ± 10μ inch finish, both epoxy and urethane are unacceptable for aluminum armor 5083 bonding.

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# INTRODUCTION

Adhesives have proven their cost effectiveness on ferrous metal bonding in the automotive industry and on alloy bonding in the aircraft industry through weight reduction and good structural bond strengths but there has been little emperical research on the effectiveness of adhesives on aluminum armor.

The purpose of this investigation was to determine the effectiveness of two generic adhesives: a two-part epoxy and a urethane adhesive, as a bonding medium for aluminum armor 5083. The effects of chemical surface preparation prior to the application of adhesive were examined also to determine the relationship between a clean and untreated surface on bond quality.

Aluminum armor 5083 test panels were grouped into the following categories: chemically cleaned urethane bonded panels, untreated urethane bonded panels, chemically cleaned epoxy bonded panels, and untreated epoxy bonded panels. The panels were lap-joined and allowed to cure under standard atmospheric conditions for a period of 14 days and were then tested for shear strengths.

## SUMMARY

The initial aim of the investigation was to test bonded aluminum armor panels to establish some maximum acceptable load limits. With these limits set, fatigue testing was to be incorporated to simulate physical conditions that bonded aluminum armor would be subjected to.

The results of the shear testing were so poor that there was no practical purpose in progressing to fatigue loading. The average shear strength of urethane bonded aluminum armor 5083 was 216 lbf/in.$^2$ for clean surfaces and 236 lbf/in.$^2$ for untreated surfaces. The average shear strength for epoxy bonded aluminum armor 5083 was 937 lbf/in.$^2$ for clean and 957 lbf/in.$^2$ for untreated surfaces. These results were contrary to the anticipated results. Generally, with adhesive bonding, the cleaner the substrate the stronger the bond.

## DISCUSSION

The objective of this investigation was to determine the effectiveness of two generic adhesives as a bonding medium between panels of aluminum armor. Questions to be addressed:

1. Without extensive surface preparation, will bond strengths prove to be adequate on aluminum armor applications?

2. Will the chosen cleaner have any effect on bond strength?

3. Under standard atmospheric conditions, are load-bearing joints capable of sustaining fatigue resistance?

Two types of adhesives were chosen for the testing: a two-part generic epoxy (PR947) and a urethane adhesive (PR366), both manufactured by Products Research and Chemical Corporation. The adhesives were picked on the basis of their high quality, desired strength specifications, and the fact that neither requires extraneous application procedures. The manufacturer's rated shear strength was 2,000 lbf/in.$^2$ and 180 lbf/in.$^2$ at 75$^\circ$F for the epoxy and urethane respectively. The investigation was initially set to test adhesive effectiveness on both 5083 and 7039 aluminum armor, but the 7039 was not available at the time of testing so the investigation proceeded using the 5083 armor only. These two aluminum armors were chosen as the substrate because of their current application in the M2/M3 fighting vehicle system.

### Cleaner Choice

Methyl Ethyl Ketone (MEK) was the chosen surface cleaner because of its desired characteristics. MEK was one of the cleaners recommended by the adhesive manufacturer. It is also a commonly used manufacturing cleaning agent that leaves no residual film and is chemically inert on aluminum.

### Adhesive Preparation

The PR947 epoxy was supplied in two-part, premeasured units. A mechanical mixer was used to combine the two parts, limiting the speed to avoid generating internal heat which will tend to reduce bonding capabilities. The PR366 urethane was supplied as a one-part, ready to apply compound. Its curing properties are catalyzed by reaction with atmospheric moisture.

### Test Panel Standards

The dimensions of the aluminum armor 5083 test panels were 1/4 in. x 2 in. x 4 in. Profilometer readings of the substrate were 60 $\pm$ 10 $\mu$ inches. Pairs of panels were divided into four groups: untreated panels to be epoxy bonded, untreated panels to be urethane bonded, and MEK treated panels to be epoxy and urethane bonded. The panels were lap-joined one inch with an adhesive thickness of not less than

1/64 in. and no greater than 1/32 in. (figure 1). The adhesive was applied in a uniform film to ensure that no bubbles or gaps occurred. The bonded panels were allowed to cure at atmospheric pressure and a temperature of $70^{o}F \pm 5^{o}$ for a period of 14 days.

## Lap Shear Test

The investigation was conducted in anticipation of testing for fatigue strengths after static shear strenghts were determined. The bonded test panels were installed on an Instron 1333 Closed Loop Servohydraulic Material Testing system. (figure 2). A Linearly increasing load was applied to the test panels and the load-stroke relationship was recorded. Typical epoxy, urethane results are shown in figure 3. The static shear strengths were too low to proceed to fatigue tests (figure 4). We felt that the flexibility and energy dissipation properties of the chosen adhesives would lead to good fatigue resistance, but results did not concur.

## Substrate Analysis

Figure 5a and b shows the epoxy and the urethane faces, respectively. As depicted, the epoxy panel separation was the result of a cohesive failure and the urethane panel failed due to an adhesive failure. As shown in figure 5a, the epoxy appears not to be fully cured. This is attributed to an epoxy Shore A rating of 50, a soft rating which may have contributed to the poor shear strength. Scanning Electron Microscope photographs (figure 6) of the aluminum/urethane interface show virtually no urethane adhesion (lack of refulgent inclusions). There was no notable difference between the treated (clean) and untreated substrate panels (figure 7a and b).

## Conclusions

The results obtained from the two generic adhesives proved that both were substandard as an effective bonding medium. Results indicate that:

1. A more extensive surface preparation may yield better shear strength. Sandblasting the surface, followed by cleaning the surface with a solvent other than MEK is an example.

2. Cleaning the aluminum surface with MEK proved to have no beneficial effects on shear strengths of the adhesive/ aluminum interface.

3. Due to the inadequate shear strengths of the adhesives on aluminum armor 5083, the fatigue resistance limits could not be evaluated.

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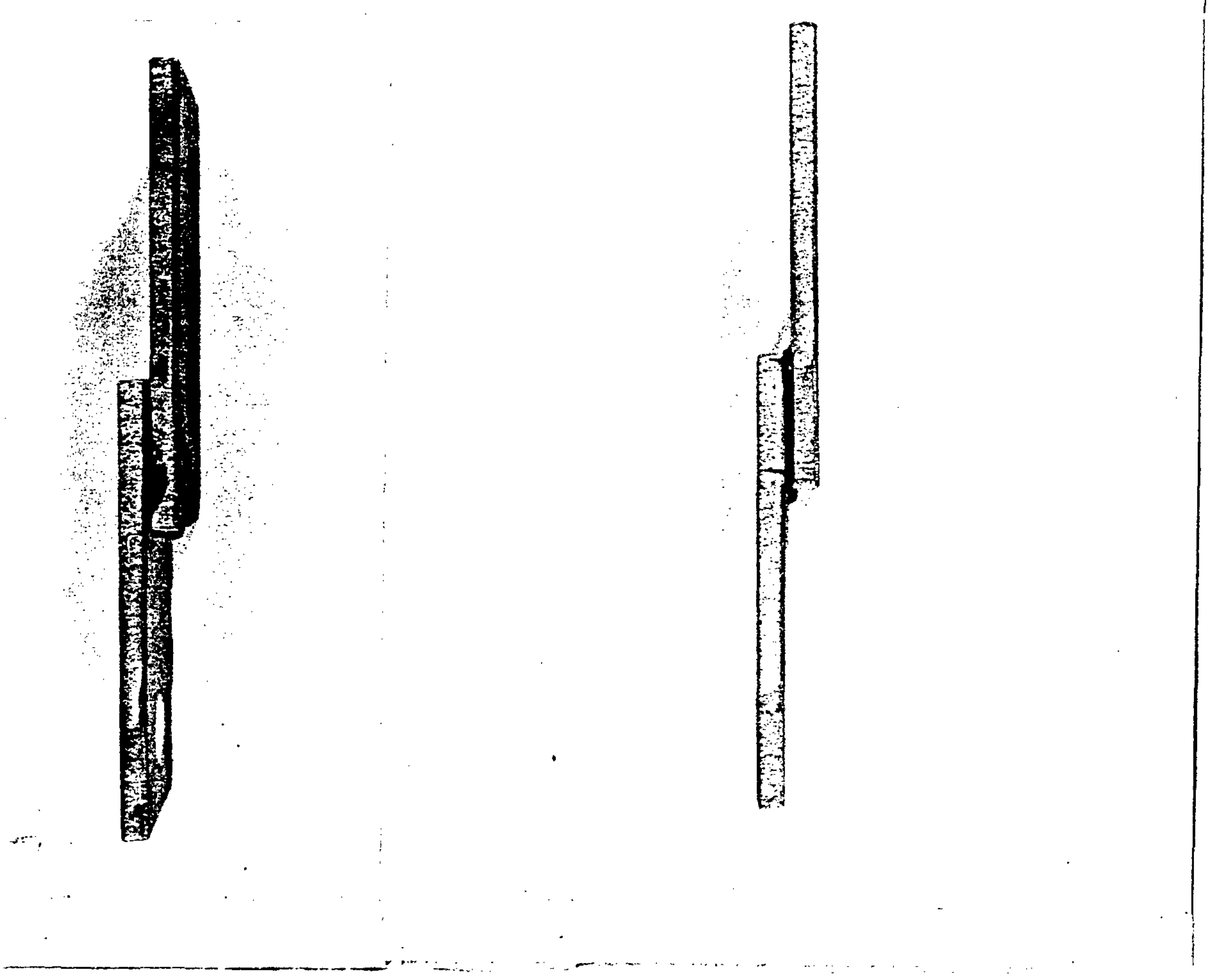


a. Epoxy Lap    b. Urethane Lap

Figure 1. Epoxy Lap and Urethane Lap - Joined Test Panel.

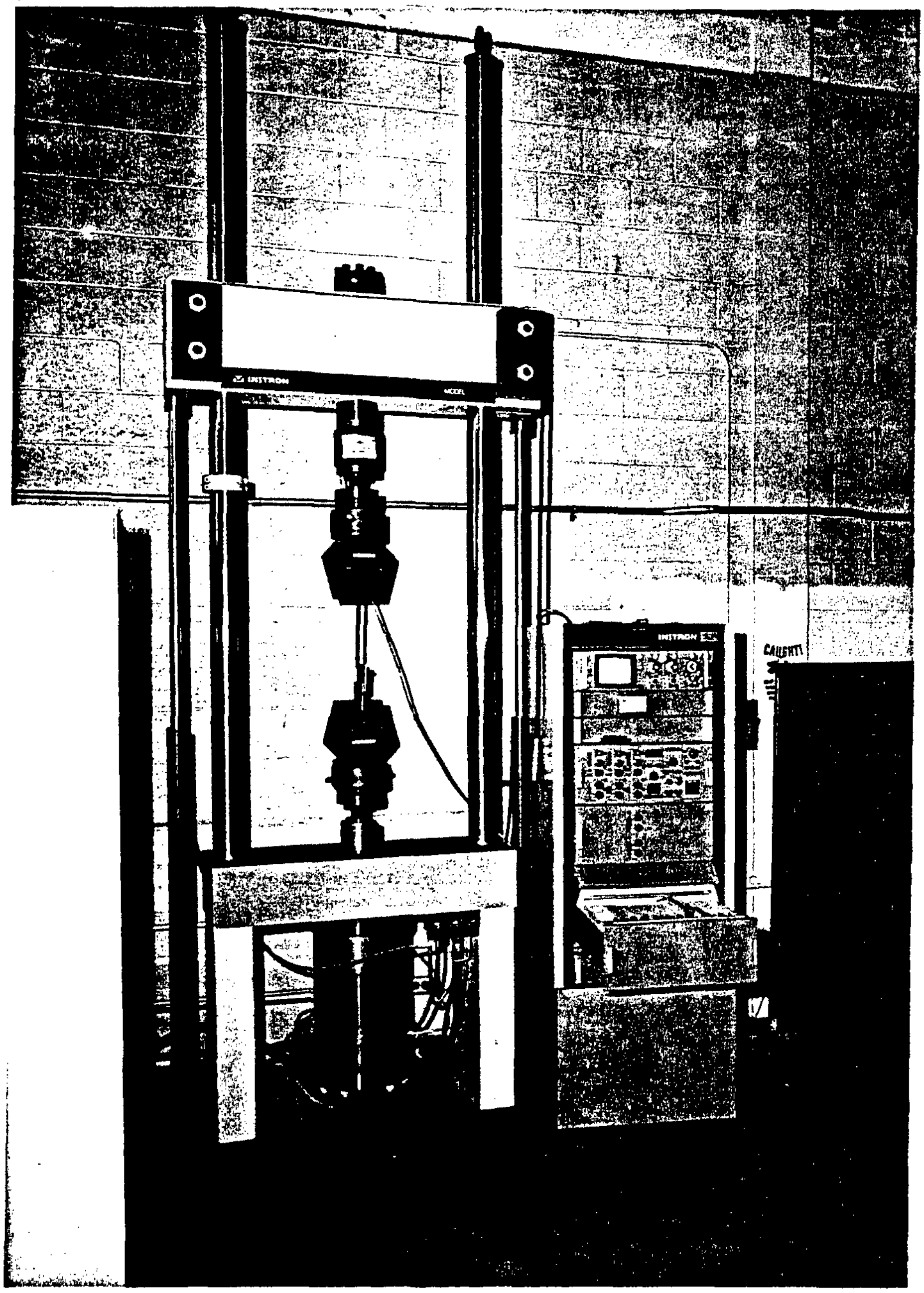
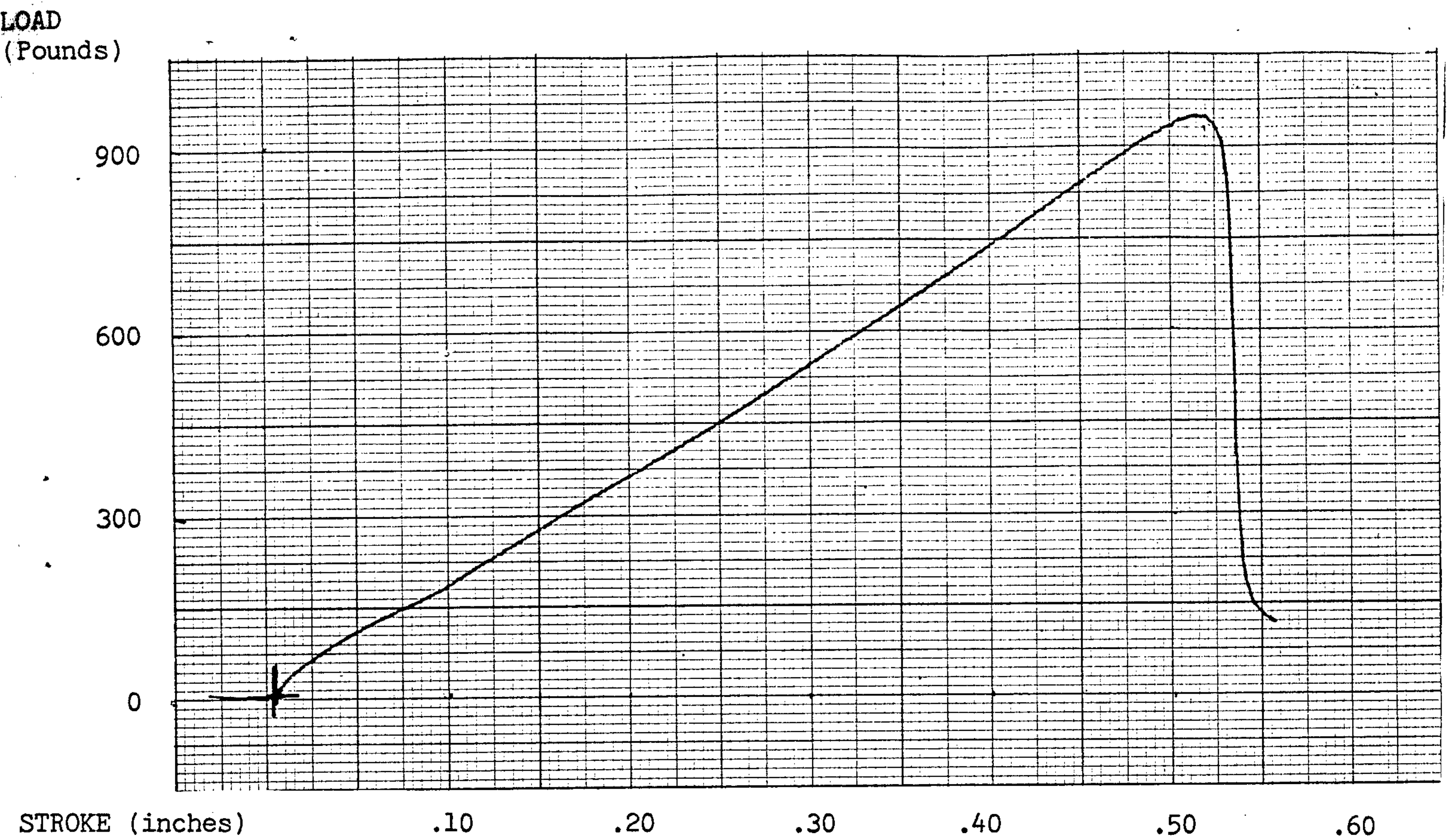
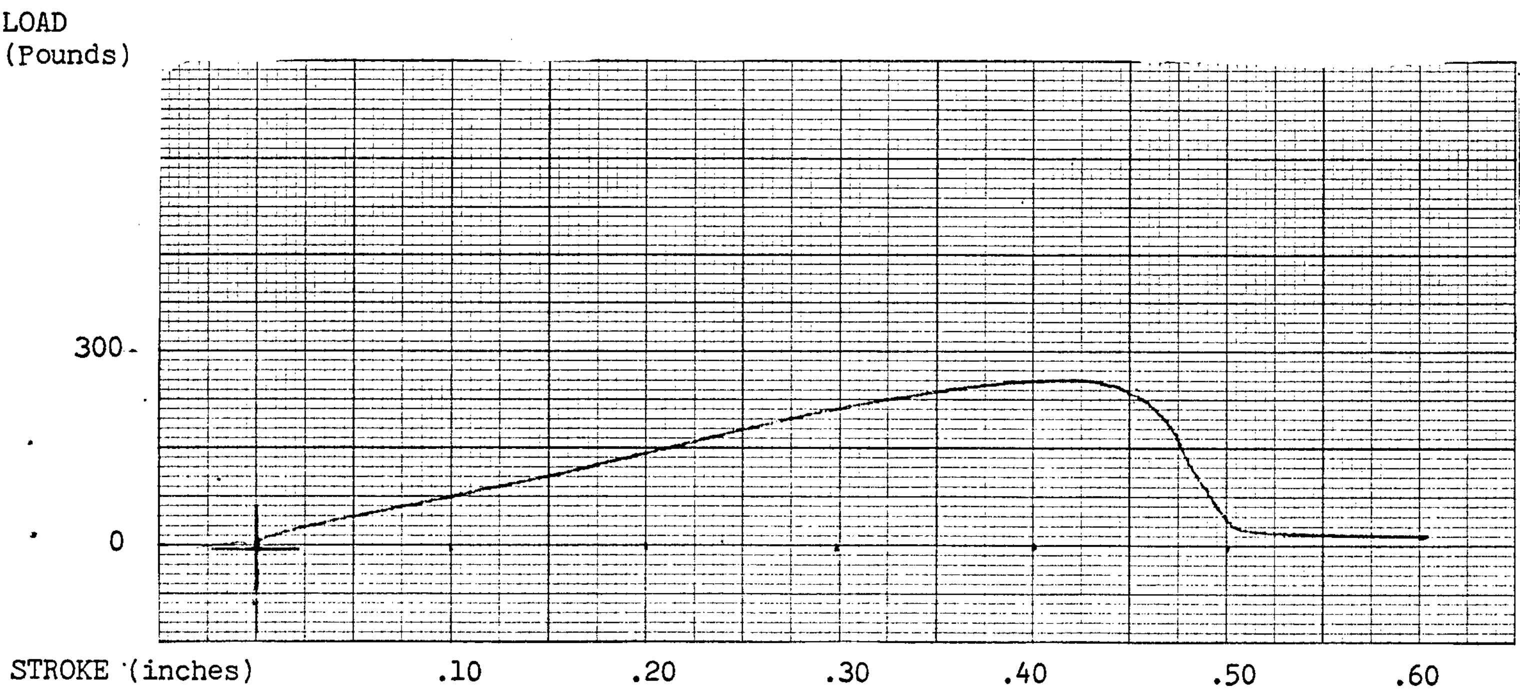



Figure 2. Instron 1333 Material Testing System




EPOXY LOAD




URETHANE LOAD

Figure 3. Typical Epoxy Load and Urethane Load - Stroke Relationship.

UNTREATED EPOXY

| Panel | Shear (psi) |
|---|---|
| 1 | 787.5000 |
| 2 | 850.0000 |
| 3 | 950.0000 |
| 4 | 1025.0000 |
| 5 | 1037.5000 |
| 6 | 1012.5000 |
| 7 | 987.5000 |
| 8 | 937.5000 |
| 9 | 975.0000 |
| 10 | 1010.0000 |

MEAN SHEAR = 957.25

ST. DEV. = 80.86726092

CLEANED EPOXY

| Panel | Shear (psi) |
|---|---|
| 1 | 962.5000 |
| 2 | 937.5000 |
| 3 | 975.0000 |
| 4 | 837.5000 |
| 5 | 950.0000 |
| 6 | 800.0000 |
| 7 | 912.5000 |
| 8 | 1025.0000 |
| 9 | 1000.0000 |
| 10 | 975.0000 |

MEAN SHEAR = 937.5

ST. DEV. = 70.46472719

UNTREATED URETHANE

| Panel | Shear (psi) |
|---|---|
| 1 | 275.0000 |
| 2 | 212.5000 |
| 3 | 200.0000 |
| 4 | 300.0000 |
| 5 | 245.0000 |
| 6 | 240.0000 |
| 7 | 240.0000 |
| 8 | 210.0000 |
| 9 | 220.0000 |
| 10 | 220.0000 |

MEAN SHEAR = 236.25

ST. DEV. = 31.20830552

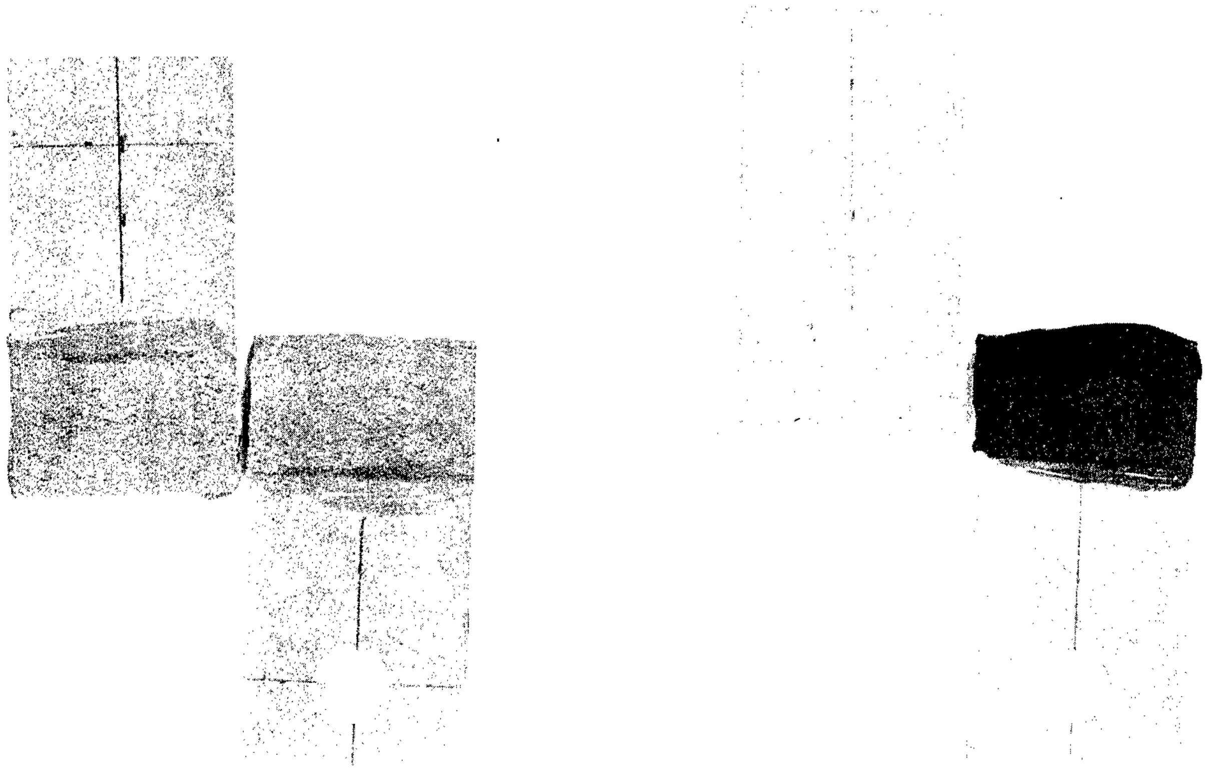
CLEANED URETHANE

| Panel | Shear (psi) |
|---|---|
| 1 | 225.0000 |
| 2 | 212.5000 |
| 3 | 225.0000 |
| 4 | 220.0000 |
| 5 | 192.5000 |
| 6 | 225.0000 |
| 7 | 220.0000 |
| 8 | 225.0000 |
| 9 | 200.0000 |
| 10 | 215.0000 |

MEAN SHEAR = 216.

ST. DEV. = 11.43823996

Figure 4. Table of Epoxy, Urethane Shear Strengths



a. Epoxy b. Urethane

Figure 5. Separated Epoxy and Urethane Test Panels

Figure 6. Scanning Electron Microscope (SEM) Photograph of Aluminum/Urethane Interface (1000X)

a. Clean

b. Untreated

Figure 7. SEM Photographs of Clean & Untreated Aluminum 5083 (1000X)

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